Preliminary Estimate of Optimum Freshwater Inflow to the Caloosahatchee Estuary: A Resource-Based Approach

Robert H. Chamberlain and Peter H. Doering

Abstract

In the Caloosahatchee Estuary, establishing a suitable salinity environment is the most basic prerequisite for promoting estuarine biota in this system. The South Florida Water Management District has adopted a resource-based research strategy with the intent of prescribing an acceptable freshwater discharge distribution within the salinity tolerance range of key estuarine species. To test this approach, submerged aquatic vegetation were selected as key species. This paper presents preliminary results and recommends a provisional inflow distribution.

Introduction

The Caloosahatchee River (canal C-43) and estuary (Figure 1) have been drastically altered to convey more basin runoff and regulatory releases from Lake Okeechobee (Chamberlain and Doering, this proceedings). These changes have caused large fluctuations in: freshwater inflow volume; frequency of inflow events; timing of discharges; and water quality in the downstream estuary. Therefore, the South Florida Water Management District (SFWMD) initiated a long-term research program in 1985 to quantify the impacts of freshwater inflow from Franklin Lock and Dam (structure S-79) on downstream estuarine organisms. Chamberlain and Doering (this proceedings) described the resource-based management approach of this program and explained that it seeks to define limits for freshwater inflow which provide a suitable salinity and water quality environment for key species. To test this research strategy, submerged vascular plants have been selected as key species.

One aspect of the estuarine research has been field monitoring of water quality and biota during a wide range of discharge events. The purpose of this paper is to report preliminary results of the relationship between freshwater inflow, salinity, submerged aquatic vegetation (SAV), and other estuarine species. These results are

based on analysis of field monitoring efforts, in order to: (1) establish provisional limits for the quantity of freshwater discharged to the estuary via S-79, and (2) examine one of the major assumptions of the resource-based approach: that environmental conditions suitable for key species also will be suitable for other important biota.

Methods

A computational salinity model developed by Bierman (1993) for the Caloosahatchee Estuary (CE) was employed to mathematically define the influence of various freshwater inflows on salinity at every 2 kilometers upstream from Shell Point to S-79. Modeling results compared freshwater inflow influence on the preferred salinity and distribution of SAV and other biota, which were determined from field sampling and the literature. The model also determined that salinity downstream to Shell Point is dependent (97%) on inflow from S-79 and that during average inflow conditions (~ 1,000 cfs) the hydraulic residence time averages about one month. Therefore, for this report, freshwater discharge to the estuary is considered in terms of mean monthly inflow from S-79.

Field observations of Vallisneria americana by Hoffacker (1994), the authors of this paper, and others (Gunter and Hall 1962, Phillips and Springer 1960), served to establish a qualitative abundance index for comparison with salinity at the time of the observation. Information from Hoffacker (1994) and the SFWMD were combined to produce a map of SAV distribution upstream of Shell Point (Figure 2).

Monthly water quality and biota sample collections occurred in three phases: phase 1 ran from 1986 into 1989 when S-79 inflows were usually low to moderate; phase 2 was conducted during 1994-1996 when discharges were often large; and two follow up sampling trips (phase 3) to evaluate seagrass recovery were conducted in 1997. Sampling centered around seven locations in phase 1 (Figure 2), areas 1-6 in phase 2, and only location 6 in 1997.

Repetitive random samples of the seagrasses, Halodule wrightii and Thalassia testudinum, were collected at locations 5-7 during phase 1 and area 6 in the remaining two phases. For this report, only the photosynthetic blades that were collected within 0.1 m^2 quadrat samples, then dried and weighed were analyzed (dry weight biomass).

For this preliminary analysis, the effects of freshwater discharge on zooplankton, ichthyoplankton, and benthic macroinvertebrates were evaluated using the data obtained during phase 1 of the SFWMD field monitoring. All data that were not normally distributed were logarithmically transformed. The biota from each station were separated into flow categories (factor levels). A simple one-factor analysis of variance (ANOVA) was calculated to test for statistical difference between the mean monthly inflow categories ($p<0.05$). A hierarchy evaluation (Scheffe multiple range test) for mean density between inflow categories was performed to determine which inflow levels were associated with significantly more or less biota. Because adult finfish, crabs, and shrimp were not sampled, we relied on literature information from the CE and other Florida estuaries to estimate desired inflow conditions for these biota.

Results and Discussion

Salinity and Freshwater Inflow

The salinity model results (Bierman 1993) indicate that more than half the estuary upstream of Shell Point will become nearly freshwater and salinity will be reduced drastically downstream during even moderate mean monthly discharges of 2,000 cfs (Figure 3). Inflows greater than 4,000 cfs will cause most of the estuary upstream of Shell Point to become freshwater and depress salinity (<15 ppt)in portions of San Carlos Bay. At the other extreme, prolonged low to no flow (<100 cfs) results in salinity conditions near S-79 that exceed 15 ppt: eliminating any tidal freshwater or oligohaline zone within the estuary.

V. americana longitudinal distribution is about 18 km during ideal growing conditions and stretches from its upstream limit at 32 km, as measured from Shell Point, to its downstream limit at 14 km (Figure 2). Based on this distribution, we estimated that over 80% of the total area covered by moderate to dense stands of V. americana under favorable growing conditions are in the first 4 km (28-32) of its

upstream limit.

Literature information indicates that V. americana growth steadily declines with increasing salinity until it ceases at approximately 8-9 ppt, but it can tolerate salinity (survive) up to 11-13 ppt (Day et al. 1989, Twilley and Barko 1990). The qualitative information assembled from observations in the CE (Figure 4) is consistent with these limits and indicates that density declines where salinity is above 10 ppt. A similar plot of biomass vs. temperature reveals no trend, suggesting little influence of temperature on V. americana distribution in this system.

Employing the results of the model by Bierman (1993: Figure 3), it appears that at least a 300 cfs mean monthly discharge from S-79 is required to maintain V. americana in the system. Analysis of historical S-79 discharges determined that attaining the 300 cfs minimum inflow will be a concern only during the November-May dry season. Therefore augmentation of flow should be considered during this time. Discharges that approach 400-500 cfs will provide salinity conditions of ≤ 10 ppt within the portion of the estuary that support most of the total V. americana coverage. To provide salinity conducive for V. americana throughout its entire 18 km range will require mean monthly discharges of approximately 800 cfs.

H. wrightii is the only seagrass species consistently found around station 5, upstream of Shell Point, until it mixes downstream with T. testudinum in San Carlos Bay (Figures 5a and b). H. wrightii has a much smaller distribution upstream of Shell Point than V. americana. It ranges only from 2-10 km upstream of Shell Pt., with the greatest coverage per 2-km segment within the 4-6 km area.

H. wrightii is reported to have a wide salinity tolerance by McMahan (1968). It does not survive below 3.5 ppt and prefers salinity as high as 44 ppt. This wide tolerance is probably why it is the only true seagrass species encountered inside the CE at station 5, although high discharges probably limit its productivity. The lowest biomass occurs inside the estuary where salinity is also lowest and most variable. Graphically and statistically, biomass of H. wrightii

is greater when salinity is above 20 ppt (Figure 6). Statistically, the greatest biomass occurs when salinity is > 28 ppt.

Literature summarized by Zieman and Zieman (1989) indicates that the optimum salinity range for T. testudinum is 24-35 ppt, with maximum photosynthetic activity occurring at 35 ppt and decreasing linearly with declining salinity. T. testudinum does not normally grow in areas where salinity is below 17 ppt. These literature values are consistent with preliminary monitoring results for the CE (Figure 5b). T. testudinum does not exist inside the estuary (in Iona Cove: area 5), where salinity during sampling was more variable, with a standard deviation that extended below 20 ppt due to long periods below 10 ppt. Like H. wrightii, the biomass of T. testudinum is statistically greater when salinity is above 20 ppt, regardless of season.

According to the Bierman model and statistical analysis, the 400-500 cfs needed to support over 80% of the V. americana, will not lower salinity below that preferred by H. wrightii (>20 ppt) anywhere in its current range. Salinity begins to approach the reported mortality limit of H. wrightii (3.5 ppt) in area 5 when average discharges approach 3,000 cfs for more than a month. Both H. wrightii and T. testudinum biomass are statistically greatest throughout their respective distributions when mean monthly inflow is less than about 800 cfs for more than two months. In San Carlos Bay, mean monthly inflows > 4,500 for two or more months are statistically associated with the least biomass for both species.

Finfish

At least 75% of Florida's recreational fishes depend on estuaries for at least a portion of their life. The most important role of estuarine systems is as a nursery area for juvenile stages (Seaman 1988). In the upper CE, Gunter and Hall (1962) reported the greatest catches in seines consisted of juveniles, during midwinter inflows that reduced salinity in the inner estuary to 1-5 ppt (station 2 area). Seine catches in the outside water (San Carlos Bay area) were greatest when salinity was high. Therefore, establishment of a minimum inflow for V. americana should generally benefit the finfish

of the estuary by providing a salinity gradient that includes desired low salinity conditions upstream for juveniles. Maintenance of this minimum flow is apparently most critical during the winter dry season. However, year round high maximum inflow limits that maintain salinity downstream of Shell Point also appear beneficial.

Bay anchovy (Anchoa mitchilli) juveniles and adults were the third most abundant fish collected by Gunter and Hall (1962), with 94% of the fish caught upstream of Shell Point. Most of the juveniles they caught were from near zero salinity water at stations close to V. americana beds at Beautiful Island and the Ft. Myers bridges. This is consistent with Jones et al. (1978), who reported that juveniles often ascend rivers above brackish waters. Therefore, inflows within the optimum range for SAV (300-800 cfs) should not adversely impact bay anchovies, and should provide better conditions for their development and food production.

Redfish (Sciaenops ocellata) are an important game fish in Florida. Spawning occurs seaward of estuary passes during late summer and fall. Seaman (1988) reported that seagrass meadows are primary habitat for young redfish. Once in the estuary, juveniles feed on benthic organisms from October to February and later on small fish and shrimp. Collections of redfish in the CE (Phillips and Springer 1960; Gunter and Hall 1962) were almost exclusively inside the estuary with salinity ranging from 0.2-14 ppt. Therefore, promoting dry season inflows conducive for SAV also will provide salinity and habitat for redfish recruitment and development.

Ichthyoplankton

Anchoa spp. comprised 76% of the SFWMD ichthyoplankton samples during 1986-1989 (unpublished data). The greatest density occurred during April-July, followed by the period of December through March. During the dry season, when inflows will need to be augmented for V. americana, high inflows > 2,500 cfs were associated with the lowest mean ichthyoplankton density, regardless of location in the estuary. Mean density within the flow category of 300-600 cfs were at least the second highest at all stations, and therefore represented the optimum overall flow category.

The presence of developing fish eggs provides a good indication of the spawning location and recruitment success of fish in an estuary. Statistical analysis of eggs within ichthyoplankton samples during the dry season found significant differences existed among inflow categories: inflows in the range of 150-600 cfs were associated with the highest mean egg density at stations 1-4; and density decreased as inflows increased above this category. In fact, no eggs were ever collected during this season at stations 1-5 when inflows were > 2,500 cfs and substantially fewer eggs were collected at station 6. Reduced egg density during high inflows are assumed to be related to a 'flush-out' effect, so similar impacts probably exist during the wet season.

Zooplankton

Zooplankton provide a crucial link in the estuarine food web when they consume free-floating microscopic plants (phytoplankton) and transfer plant energy to higher trophic levels. Dominant forage fishes such as bay anchovy, as well as juvenile stages of most estuarine fish species, depend on zooplankton as a food source.

Within each season, mean zooplankton density increased with increasing salinity and distance from S-79. In general, zooplankton density was greatest during April-July. Collections during this time period appeared sensitive to high flows. Inflows greater than 1,500 cfs resulted in the lowest mean density at all stations. Evaluation of dry season inflow (November-May) revealed significant lower density with flows > 1,200 cfs. Zooplankton mean density associated with inflows between 300-600 cfs were consistently among the greatest encountered at each station.

Invertebrates

In the Little Manatee River (southwest Florida), Peebles and Flannery (1992) reported that transfer of the estuary's food source to juvenile fish appeared to occur largely through their feeding on benthic organic material. Therefore, the density of benthic organisms can strongly influence the survival of many higher trophic species. The

SFWMD benthic macroinvertebrate survey (unpublished data) found that the CE supports a large number of species (519). The majority of these are sessile and can't relocate to a more favorable location when water quality deteriorates. CE inflows within the optimum range for V. americana appear conducive for supporting a wide range of benthic infauna. Statistical analysis of dry season data indicate that peak benthic macroinvertebrate density at stations 1-4 was associated with inflows (150-600 cfs) that establish salinity in approximately the mesohaline range (5-18 ppt). This same preliminary analysis also indicated that mean monthly discharges > 3,000 cfs are associated with the lowest densities at stations 1-4.

Penaeid shrimp probably represent the most economically important fishery in Florida (Seaman 1988). Mating and spawning occurs offshore and the postlarvae migrate into the estuary and seek shallow areas with vegetation and/or abundance of organic detritus. The loss of SAV directly reduces fishery yields (Seaman 1988). Gunter and Hall (1962) indicated pink shrimp (Penaeus duorarum) were common in seine and net samples in the CE. Haunert (1987) reported pink shrimp abundance increased after inflows increased in the St. Lucie Estuary, but decreased when inflows caused salinity to decline to oligohaline conditions (< 5 ppt), which are not tolerated well by pink shrimp (McFarland and Lee 1963; Gunter et al. 1964). Therefore, in the CE, minimum and maximum inflows that promote SAV at both the inner estuary and the Iona Cove-San Carlos Bay regions should provide ideal salinity for pink shrimp and support bottom vegetation habitat important for postlarvae development.

The CE supports a year-round commercial and sport fishery for blue crabs (Callinectes sapidus). This species also is an important source of food for many fish. The first development stages are planktonic, which prefer 30 ppt and will perish if exposed to salinity < 20 ppt (Millikin and Williams 1984). After settling out of the plankton, each subsequent juvenile phase of both sexes is concentrated in progressively lower salinity because of their continuing migration up the estuary (Millikin and Williams 1984). Juvenile and adult blue crabs also occur in much higher densities in areas covered by vegetation. Therefore, inflows in the range of 300-800 will be

beneficial for blue crabs because of their salinity requirements throughout the CE, as well as the SAV habitat that these flows promote in both the inner and outer estuary.

Estimate of optimum inflow

Table 1 recommends provisional inflow ranges and timing for maintaining the health of the important taxa discussed above and others. The preliminary analysis suggests that a minimum inflow of 300 cfs for V. americana during the dry season will not be harmful, but inflows greater than about 2,500-3,000 cfs may be detrimental to other biota anytime of the year. Therefore, a distribution of inflows that has the greatest frequency range from 300 to <1,500 cfs, with a peak of 300-800 cfs, should be generally beneficial to all the biota evaluated.

Beyond identifying the optimal timing and distribution of inflow, we also must consider that freshwater inflow varies naturally as a function of rainfall. Inclusion of this natural variation is important to insuring a diverse composition of estuarine biota. Ultimately, this will mean a defined percent of violations should be allowed for both the high and low discharge limits As a first attempt to define this environmentally sensitive distribution of S-79 discharges, a optimization program (computer model) was employed (Labadie 1995, Otero et al. 1995). The program utilized historic watershed runoff data during 1966-1990 (without Lake Okeechobee releases). The desired inflow ranges (limits for the biota) are input variables to the model, along with the natural periodicity of violations of the upper and lower limits (estimated from the 1966-1990 historic data). For the Caloosahatchee Estuary, 20.5% violation of the lower limit and 5.5% violations of the upper limit created inflows that emulated the natural variability established from rainfall during 1966-1990. In addition to natural variation, the resulting frequency distribution generated by the model (Table 2) reveals that: (1) the appropriate inflow limits were attained (300-2,800 cfs); and (2) the greatest frequency of inflows were within the range from 300-1300 cfs, with a peak of inflows between 300-800 cfs.

The above-recommended optimum flow distribution is provisional, based on the data currently evaluated, preliminary model results, and our best professional judgement. A final distribution will be established after a better understanding of the salinity tolerances of seagrass and other species is determined. This will be accomplished by: conducting a more detailed evaluation of the field data than provided in this summary; and completing field and lab experiments, which have already begun.

Acknowledgements

The resource-based strategy was based on peer reviewed guidelines developed by Mote Marine Laboratory for SFWMD estuarine research, and applied in the St. Lucie Estuary. Mote Marine Laboratory also identified and enumerated the organisms contained in the Caloosahatchee samples. The field work, sample processing, and data management depended on the effort of many SFWMD staff, most notably Dan Crean and Kathy Haunert.

Literature Cited

Bierman, V. 1993. Performance Report for the Caloosahatchee Estuary salinity modeling. SFWMD expert assistance contract deliverable from Limno-Tech, Inc.

Day, J.W., C.A.S. Hall, W.M. Kemp, and A. Yanez-Arancibia. 1989. Estuary Ecology. John Wiley and Sons, Inc. 558 pp.

Gunter, G., J.Y. Christmas, and R. Killebrew. 1964. Some relations of salinity to population distributions of motile estuarine organisms with special reference to penaeid shrimp. Ecology 45:181-185.

Gunter, G. and G.E. Hall. 1962. Biological investigation of the Caloosahatchee Estuary in connection with Lake Okeechobee discharges through the Caloosahatchee River. Consultant report to the U.S. Corps of Engineers, Jacksonville District. Serial No. 25, 59 pp.

Haunert, D.E. 1987. A proposed supplemental water management strategy to enhance fisheries in the St. Lucie Estuary, Florida. SFWMD Draft Report.

Hoffacker, V.A. 1994. Caloosahatchee River submerged grass observations. W. Dexter Bender and Associates, Inc. Letter-report and map to Chip Merriam, SFWMD.

Jones, P.W., F.D. Martin and J.D. Hardy, Jr. 1978. Development of fishes of the Mid-Atlantic Bight, vol. 1, Acipenseridae through Ictaluridae. U.S. Dept. Interior, Fish and Wildl. Serv. 366 pp.

Labadie, P.W. 1995. Optimization of managed runoff to the St. Lucie Estuary. Final contract report for SFWMD, P.O. No. PC P60617. 38 pp.

McFarland, W.N., and B.D. Lee. 1963. Osmotic and ionic concentrations of penaeidean shrimps of the Texas coast. Bull. Mar. Sci. Gulf Caribb. 13:391-417.

McMahan, C.A. 1968. Biomass and salinity tolerance of shoal grass and manatee grass in Lower Laguna Madre, Texas. J. Wildl. Manage. 33:501-506.

Millikin, M.R. and A.B. Williams. 1984. Synopsis of biological data on the blue crab, Callinectes sapidus Rathbun. NOAA Tech. Rep. NMFS 1, FAO Fisheries Synopsis No. 138, 39 pp.

Otero, J.M., J.W. Labadie, D.E. Haunert, and M.S. Daron. 1995. Optimization of managed runoff to the St. Lucie Estuary. In: Water Resources Engineering, Volume 2. W.H. Espey, Jr. and P.G. Cobbs (ed). Proceedings of First Intern. Conf., Water Resources Engineering and Amer. Soc. Civil Engineers (ASCE), pages 1506-1510.

Peebles, E.B. and M.S. Flannery. 1992. Fish nursery use of the Little Manatee River estuary (Florida): relationships with freshwater discharge. Final Rep. for Southwest Florida Water Management District, 91 pp.

Phillips, R.C. and V.G. Springer. 1960. A report on the hydrography, marine plants, and fishes of the Caloosahatchee River area, Lee County, FL. FL. State Bd. Conserv., Marine Lab. Special Science

Report. No.5, 34 pp.

Seaman, W., Jr. (ed). 1988. Florida aquatic habitat and fishery resources. FL Chapter, American Fisheries Society, 543 pp.

Twilley, R.R. and J.W. Barko. 1990. The growth of submerged macrophytes under experimental salinity and light conditions. Estuaries 13: 311-321.

Zieman, J.C. and R.T. Zieman. 1989. The ecology of the seagrass meadows of the west coast of Florida: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.25). 155 pp.

Authors Address:

South Florida Water Management District
Ecosystem Restoration Department
3301 Gun Club Road
West Palm Beach, FL 33406